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[Document Name] Specification

[Title of the Invention] LIGHT EMITTING DIODE AND DISPLAY DEVICE USING THE SAME

[What is claimed is]

[Claim 1] A light emitting diode comprising a LED chip and a photoluminescent fluorescent substance which absorbs at least a part of light emitted by the LED chip to emit light by converting the wavelength, wherein

the LED chip is a nitride compound semiconductor and the photoluminescent fluorescent substance is an yttrium-aluminum-garnet fluorescent substance activated with cerium.

[Claim 2] The light emitting diode according to claim 1, wherein a main peak of an emission spectrum of the LED chip as the nitride compound semiconductor has an emission wavelength within the range from 400 nm to 530 nm.

[Claim 3] A light emitting diode comprising a LED chip and a photoluminescent fluorescent substance which absorbs at least a part of light emitted by the LED chip to emit light by converting the wavelength, wherein

the LED chip is a gallium nitride compound semiconductor and the photoluminescent fluorescent substance is a $(RE_{1-x}Sm_x)_3(Al_yGa_{1-y})_5O_{12}:Ce$ fluorescent substance where $0 \le x < 1$ and $0 \le y \le 1$ and RE is at least one selected from Y and Gd.

[Claim 4] The light emitting diode according to claim 3, wherein a main peak of an emission spectrum of the LED chip as the

gallium nitride compound semiconductor has an emission wavelength within the range from 400 nm to 530 nm.

[Claim 5] A light emitting diode comprising a LED chip placed in a cup of a mount lead, an inner lead electrically connected with the LED chip with a conductive wire, a coating material filling the cup and a molding material covering at least part of the coating material, the LED chip, the conductive wire, the mount lead and the inner lead, wherein

the LED chip is a gallium nitride compound semiconductor and the coating material is a translucent resin containing $(RE_{1-x}Sm_x)_3(Al_yGa_{1-y})_5O_{12}$:Ce fluorescent substance where $0 \le x < 1$ and $0 \le y \le 1$ and RE is at least one selected from Y and Gd.

[Claim 6] A light emitting diode according to claim 1, 3 or 5, wherein the composition of the photoluminescent fluorescent substance is represented by the following general formula:

$(Y_{1-p-q-r}Gd_pCe_qSm_r)_3(Al_yGa_{1-y})_5O_{12}$

where $0 \le p \le 0.8$

$0.003 \le q \le 0.2$

$0.0003 \le r \le 0.08$

$0 \le s \le 1$

[Claim 7] A LED display device comprising a LED display provided with the light emitting diodes of claim 5 in the matrix form, and a drive circuit electrically connected with the LED display.

[Detailed Description of the Invention]

[0001]

[Industrial Utilization Field]

The present invention relates to a light emitting diode which is used in LED display, back light source, signal, illuminating switch, indicator, etc. More particularly, it relates to a light emitting diode having photoluminescent fluorescent substance, which converts light emitted by a LED chip that is a light emitting element and emits light, and providing high luminance and high efficiency regardless of the operating environment, and a display device using the same.

[0002]

[Prior Art]

A light emitting diode (hereinafter referred to as LED) is compact and emits light of clear color with high efficiency. It is also free from such a trouble as burn-out because it is a semiconductor element. It has an excellent initial drive characteristic and such an advantage as durability to endure vibration and repetitive ON/OFF operations. Thus it has been used in applications as various indicators and various light sources. Recently light emitting diodes for RGB (red, green and blue) colors having ultra-high luminance and high efficiency have been developed. Accordingly, LED displays using the three primary colors of RGB have been greatly advancing by making most of the advantages such as low power consumption, long life and light weight.

[0003]

The light emitting diode can emit light of various wavelengths ranging from ultra violet to infrared, depending on the semiconductor material and conditions to form a light emitting layer to be used. It also has favorable emission spectrum to generate monochromatic light.

[0004]

Although because the light emitting diode has favorable emission spectrum to generate monochromatic light, making a light source for white light requires it to arrange the LED chips which are capable of emitting light of RGB colors closely to each other while diffusing and mixing the light emitted by them. Although these light emitting diodes are effective as light emitting devices for emitting various colors freely, a set of red green and blue light emitting diodes or a set of blur-green and yellow light emitting diodes must be used even when generating white light only. A LED chip is a semiconductor and still includes considerable variations in the color tone and luminance. Also in case the LED chips which are semiconductor light elements are made from different materials, different LED chips require different drive voltages which must be supplied from different power sources provided separately. Therefore, white light must be generated by adjusting the current for each semiconductor. Similarly, color tone is subject to variation due to the difference in temperature characteristics and chronological changes, because the LED chips are semiconductor light emitting elements. Further, uneven color

may result unless the light rays emitted by the LED chips are mixed evenly.

[0005]

Thus the present applicant previously developed light emitting diodes which convert the color of light emitted by a LED chip by means of a fluorescent substance disclosed in Japanese Patent Kokai Nos. 5-152609 and 7-99345. By using these light emitting diodes, light of other colors such as white color can be emitted by using a LED chip of one type.

[0006]

Specifically, a LED chip having a large energy band gap of light emitting layer is arranged in a cup provided at the tip of lead frame. The LED chip is electrically connected to a metal stem or metal post where the LED chips are provided. Then a fluorescent substance which absorbs the light emitted by the LED chip and converts the wavelength is contained in the resin molding material which covers the LED chip.

[0007]

As a light emitting diode which converts the wavelength of light emitted by a LED chip, such a light emitting diode can be used which can emit white light by mixing light emitted by a blue light emitting diode and yellow light emitted by a fluorescent substance which absorbs the light emitted by the blue light emitting diode. These light emitting diodes can emit light with sufficient luminance even when used to emit white light.

[0008]

[Problems to be solved by the Invention]

There are various fluorescent substances such as fluorescent dye, fluorescent pigment and organic or inorganic compounds which are excited by light emitted by a light emitting diode. Also there are fluorescent substances which convert light of shorter wavelength emitted by a light emitting element into light of longer wavelength and those which convert light of longer wavelength emitted by a light emitting element into light of shorter wavelength.

[0009]

However, efficiency of conversion of long-wavelength light into short-wavelength light is extremely low and is not practical. A fluorescent substance arranged close to a LED chip is exposed to light of a radiation intensity as high as about 30 to 40 times that of sun light. Especially when a LED chip as a light emitting element is made by using a semiconductor having a high energy band gap to improve the conversion efficiency of the fluorescent substance and reduce the quantity of the fluorescent substance consumed, light energy inevitably increases even though the light emitted by the LED chip falls within visible light range. In this case, when the emission intensity is increased and used for a long period of time, the fluorescent substance can deteriorate. There is such case as the color tone changes as the fluorescent substance deteriorates or such a case as the fluorescent substance

is blackened resulting in lowered efficiency of extracting light. Similarly, the fluorescent substance provided in the vicinity of the LED chip is exposed to a high temperature such as rising temperature of the LED chip and from the external environment. Further, although a light emitting diode is usually sealed in a resin molding, it is impossible to completely prevent the entry of moisture from the outside or to completely remove moisture which was contained during production. In the case of some fluorescent substances, such moisture accelerates the deterioration of the fluorescent substance due to the high-energy radiation or heat transmitted from the light emitting element. When it comes to an organic dye of ionic property, direct current electric field in the vicinity of the chip may cause electrophoresis, resulting in a change in the color tone. Therefore, the present invention is intended to solve the problems described above and provide a light emitting diode which is subject only to extremely low degrees of deterioration in light emission efficiency and color shift over a long period of time with high luminance.

[0010]

[Means for Solving the Problems]

The light emitting diode of claim 1 of the present invention comprises a LED chip and photoluminescent fluorescent substance which absorbs at least a part of the light emitted by the LED chip to emit light by converting the wavelength. The LED chip is a nitride compound semiconductor and the photoluminescent

fluorescent substance is an yttrium-aluminum-garnet fluorescent substance activated with cerium.

[0011]

With respect to the light emitting diode of claim 3 of the present invention, the LED chip is a gallium nitride compound semiconductor and the photoluminescent fluorescent substance is a $(RE_{1-x}Sm_x)_3(Al_yGa_{1-y})_5O_{12}$:Ce fluorescent substance, where $0 \le x < 1$ and $0 \le y \le 1$, and RE is at least one selected from among Y and Gd.

[0012]

Further, with respect to the light emitting diode of claims 2 and 4 of the present invention, the main peak of the emission spectrum of the LED chip as the gallium nitride compound semiconductor has an emission wavelength within the range from 400 nm to 530 nm.

[0013]

The light emitting diode of claim 5 of the present invention comprises a LED chip placed in a cup of a mount lead, an inner lead electrically connected with the LED chip by means of a conductive wire, a coating material filling the cup and a molding material covering at least part of the coating material, the LED chip, the conductive wire, the mount lead and the inner lead. With respect to this light emitting diode, the LED chip is a gallium nitride compound semiconductor and the coating material is a translucent resin containing $(RE_{1-x}Sm_x)_3(Al_yGa_{1-y})_5O_{12}$:Ce fluorescent substance is used the coating material, where $0 \le x < 1$

and $0 \leq y \leq 1$, and RE is at least one selected from Y and Gd.

[0014]

Further, with respect to the light emitting diode of claim 6 of the present invention, the photoluminescent fluorescent substance represented by the following general formula:

$(Y_{1-p-q-r}Gd_pCe_qSm_r)_3(Al_yGa_{1-y})_5O_{12}$

where $0 \leq p \leq 0.8$

$0.003 \leq q \leq 0.2$

$0.0003 \leq r \leq 0.08$

$0 \leq s \leq 1$

[0015]

Also the display device of claim 7 of the present invention comprises a LED display provided with the light emitting diodes of claim 5 in the matrix form, and a drive circuit electrically connected with the LED display.

[0016]

[Mode for carrying out the Invention]

The present inventors have found, as a result of various experiments, that it is made possible to prevent the decrease in emission efficiency and color shift through operation with a high luminance over a long period of time by selecting a particular semiconductor and a fluorescent substance in a light emitting diode which uses a photoluminescent fluorescent substance to convert the color of light emitted by a LED chip having a relatively high radiation energy in visible region, and have achieved the present

invention.

[0017]

The photoluminescent fluorescent substance used in the light emitting diode must satisfy the following requirements:

1. Excellent resistance against light, particularly durability to endure light of a radiation intensity as high as about 30 to 40 times that of sun light, because the fluorescent substance is exposed to intense radiation from a tiny region such as a semiconductor light emitting element.

2. Capability to emit light in blue region, not ultra violet, because mixing of colors with the light emitting elements is used.

3. Capability to emit light from green to red regions in consideration of mixing with blue light.

4. Good temperature characteristic suitable for location in the vicinity of the light emitting element.

5. Capability to continuously change the color tone in terms of the proportion of composition or ratio of mixing a plurality of fluorescent substances.

6. Weatherability for the operating environment of the light emitting diode.

[0018]

As materials that satisfy the above requirements, the present invention uses a gallium nitride compound semiconductor element having high-energy band gap in the light emitting layer

as the light emitting diode, and yttrium-aluminum-garnet fluorescent substance activated with cerium as the photoluminescent fluorescent substance, in combination. This makes it possible to make a light emitting diode which experiences color shift of emitted light and a decrease in luminance of the emitted light, both of very low degrees, even when irradiated with high-energy radiation in the visible light region emitted by the light emitting element in the vicinity thereof over a long period of time.

[0019]

One embodiment of the light emitting diode is shown in Fig. 1 and a chip type LED is shown in Fig. 2 in sectional view. A LED chip 202 employing gallium nitrate semiconductor is fixed in the casing 204 of the chip type LED by means of an epoxy resin or the like. Electrodes of the LED chip 202 and electrodes 205 provided on the casing are electrically connected by means of gold wires which are conductive wires 203. The epoxy resin with $(RE_{1-x}Sm_x)_3(Al_yGa_{1-y})_5O_{12}$:Ce fluorescent substance mixed and dispersed therein is applied uniformly as a molding material 201 for the protection of the LED chip and the conductive wires from extraneous stresses. The LED chip 202 is caused to emit light by supplying electric power to the light emitting diode. By mixing light emitted by the LED chip 202 and light emitted by the photoluminescent fluorescent substance excited by the light emitted by the LED chip, the light emitting diode can emit light of white color.

Constituents of the present invention will now be described below.

[0020]

(Fluorescent substance)

The photoluminescent fluorescent substance used in the light emitting diode of this invention is a photoluminescent fluorescent substance which emits light when excited by visible light or ultra violet light emitted by the semiconductor light emitting element. Specifically, the photoluminescent fluorescent substance is yttrium-aluminum-garnet fluorescent substance activated with cerium. More specifically, it has a composition of $(RE_{1-x}Sm_x)_3(Al_yGa_{1-y})_5O_{12}$:Ce (where $0 \le x < 1$ and $0 \le y \le 1$, and RE is at least one selected from Y and Gd). In case the light emitted by the LED chip employing the gallium nitride compound semiconductor and the light emitted by the photoluminescent fluorescent substance having yellow body color are in the relation of complementary colors, display with white color can be achieved by mixing light emitted by the LED chip and the light emitted by the photoluminescent fluorescent substance. Therefore, it is necessary that light emitted by the LED chip and the light emitted by the photoluminescent fluorescent substance transmit through the molding material to the outside of the light emitting diode. Thus the light emitting diode may also be made in such a construction as the LED chip is enclosed in a bulk layer of photoluminescent fluorescent substance and the photoluminescent fluorescent substance is provided with two or more apertures which allow the light from the LED chip to pass. Such

a construction may also be employed as the photoluminescent fluorescent substance in the form of powder is contained in a resin or glass which is formed into a thin layer enough to allow the light from the LED chip to pass through. It is made possible to provide a desired color tone such as white and the color of incandescent lamp light, by controlling the proportions of the photoluminescent fluorescent substance and the resin and the amounts of coating or filling, and by selecting the wavelength of light emitted by he light emitting element.

[0021]

Distribution of the photoluminescent fluorescent substance concentration has influence also on the color mixing and durability. That is, when the concentration of photoluminescent fluorescent substance increases from the surface of the coating or molding where the photoluminescent fluorescent substance is contained toward the LED chip, it is less likely to be affected by extraneous moisture thereby making it easier to suppress the deterioration due to moisture. On the other hand, when the concentration of photoluminescent fluorescent substance increases from the LED chip toward the surface of the molding, it becomes more likely to be affected by extraneous moisture, but less likely to be affected by the heat and radiation from the LED chip, thus making it possible to suppress the deterioration of the photoluminescent fluorescent substance. Such distributions of the photoluminescent fluorescent substance concentration can be

achieved by selecting or controlling the material which includes the photoluminescent fluorescent substance, forming temperature and viscosity, and the construction and particle distribution of the photoluminescent fluorescent substance. Therefore, various distributions of the photoluminescent fluorescent substance concentration can be selected according to the operating conditions.

[0022]

By using the photoluminescent fluorescent substance of the present invention, the light emitting diode can be given enough light resistance for high-efficient operation even when arranged adjacent to or in the vicinity of the LED chip with radiation illuminance (Ee) in a range from 3 Wcm^{-2} up to 10 Wcm^{-2}.

[0023]

The photoluminescent fluorescent substance used in the present invention is, because of garnet structure, resistant to heat, light and moisture, thereby to be capable of absorbing excitation light having a peak at a wavelength near 450 nm as shown in Fig. 4. It also emits light of broad spectrum having a peak near 530 nm tailing out to 700 nm as shown in Fig. 4. Moreover, wavelength of the emitted light is shifted to a shorter wavelength by substituting part of Al of the composition with Ga, and the wavelength of the emitted light can be shifted to a longer wavelength by substituting part of Y of the composition with Gd. In this way, the light color of emission can be changed continuously by changing

the composition. Also the fluorescent substance is hardly excited by Hg emission lines such as 254 nm and 365 nm, but is excited with higher efficiency by light emitted by a blue LED chip of a wavelength such as 450 nm. Thus the photoluminescent fluorescent substance has ideal characteristics for converting blue light of nitride semiconductor into white light, such as the capability of continuously changing the intensity of light of long wavelengths in terms of the proportion of Gd.

[0024]

The efficiency of light emission can be further improved by making a light emitting diode containing a LED chip employing gallium nitride semiconductor and photoluminescent fluorescent substance made by adding rare earth element samarium (Sm) in yttrium-aluminum-garnet fluorescent substances (YAG) activated with cerium.

[0025]

Material for making such a photoluminescent fluorescent substance is made by using oxides of Y, Gd, Ce, Sm, Al and Ga or compounds which can be easily converted into these oxides at high temperatures, and mixing these materials well in stoichiometrical proportions. Otherwise, a mixture material is obtained by dissolving rare earth elements Y, Gd, Ce and Sm in stoichiometrical proportions in an acid, coprecipitating the solution with oxalic acid and sintering the coprecipitate to obtain an oxide of the coprecipitate, which is then mixed with aluminum oxide and gallium

oxide. This mixture is mixed with an appropriate quantity of a fluoride such as ammonium fluoride used as a flux, and sintered in a crucible at a temperature from 1350 to 1450 °C in air for 2 to 5 hours. Then the sintered material is ground by ball mill in water, washed, separated, dried and sieved thereby to obtain the desired material.

[0026]

The photoluminescent fluorescent substance having the composition of $(Y_{1-p-q-r}Gd_pCe_qSm_r)_3(Al_yGa_{1-y})_5O_{12}$ can emit light of long wavelengths of 460 nm and longer with higher efficiency upon excitation, because Gd is contained in the crystal. When the content of gadolinium is increased, peak wavelength of emission shifts from 530 nm to a longer wavelength up to 570 nm, while the entire emission spectrum shifting to longer wavelengths. When light of stronger red color is needed, it can be achieved by increasing the amount of Gd added for substitution. When the content of gadolinium is increased, luminance of photoluminescence with blue light gradually decreases. Therefore, value of p is preferably 0.8 or lower, or more preferably 0.7 or lower. Further more preferably it is 0.6 or lower.

[0027]

The fluorescent substance having the composition of $(Y_{1-p-q-r}Gd_pCe_qSm_r)_3(Al_yGa_{1-y})_5O_{12}$ containing Sm has less dependence on temperature regardless of the increased content of Gd. The photoluminescent fluorescent substance, when Sm is contained as

described above, provides greatly improved emission luminance at higher temperatures. Extent of the improvement increases when the Gd content is increased. That is, it was found that greater improvement of temperature characteristic by the addition of Sm can be achieved when Gd content is increased to give red color to the color tone of light emitted by the photoluminescent fluorescent substance. The temperature characteristic mentioned here is measured in terms of the ratio (%) of emission luminance of the fluorescent substance at a high temperature (200 °C) relative to the emission luminance of exciting blue light of wavelength 450 nm at the normal temperature (25 °C).

[0028]

Content of Sm is preferably in a range of $0.0003 \le r \le 0.08$ to give temperature characteristic of 60% or higher. Value of r below this range leads to less effect of improving the temperature characteristic. When the value of r is above this range, on the contrary, the temperature characteristic deteriorates. Range of $0.0007 \le r \le 0.02$ where temperature characteristic becomes 80% or higher is the most desirable.

[0029]

When Ce content is within the range $0.003 \le q \le 0.2$, relative emission luminance becomes 70% or higher. When the value of q is 0.003 or lower, luminance decreases because the number of excited emission centers of photoluminescence due to Ce decreases and, when the q is greater than 0.2, density quenching occurs.

[0030]

For the photoluminescent fluorescent substance used in the light emitting diode of the present invention, a mixture of two or more kinds of photoluminescent fluorescent substances having compositions of $(RE_{1-x}Sm_x)_3(Al_yGa_{1-y})_5O_{12}$:Ce may also be used. That is, RGB components can be increased by mixing two or more kinds of photoluminescent fluorescent substances having compositions of $(RE_{1-x}Sm_x)_3(Al_yGa_{1-y})_5O_{12}$:Ce having different contents of Al, Ga, Y and Gs or Sm. This, with the addition of a color filter, can also be used for a full-color liquid crystal display device.

[0031]

(LED chips 202, 202, 702)

The LED chip is preferably embedded in a molding material 104 as shown in Fig. 1. The LED chip used in the light emitting diode of the present invention is a nitride compound semiconductor capable of efficiently exciting the yttrium-aluminum-garnet fluorescent substances activated with cerium. The LED chip which is the light emitting element is made by forming a light emitting layer of semiconductor such as InGaN on a substrate in the MOCVD process. The semiconductor structure may be homostructure, heterostructure or double-heterostructure which have MIS junction, PIN junction or PN junction. Various wavelengths of emission can be selected depending on the material of the semiconductor layer and the crystalinity thereof. It may also be made in a single quantum well structure or multiple quantum well structure where

a semiconductor active layer is formed in a thin film where quantum effect can occur. Particularly in the present invention, a light emitting diode capable of emitting with higher luminance without deterioration of the photoluminescent fluorescent substance can be made by making the active layer of the LED chip in single quantum well structure of InGaN.

[0032]

When a gallium nitride compound semiconductor is used, sapphire, spinnel, SiC, Si, ZnO or the like is used as the semiconductor substrate. Use of sapphire substrate is preferable in order to form gallium nitride of good crystalinity. A buffer layer of GaN, AlN, etc. is formed on the sapphire substrate, and gallium nitride semiconductor having PN junction is formed thereon. The gallium nitride semiconductor has N type conductivity under the condition of not doped with any impurity. In order to form an N type gallium nitride semiconductor having desired properties such as improved light emission efficiency, it is preferably doped with N type dopant such as Si, Ge, Se, Te, and C. In order to form a P type gallium nitride semiconductor, on the other hand, it is preferably doped with P type dopant such as Zn, Mg, Be, Ca, Sr and Ba. Because it is difficult to turn a gallium nitride compound semiconductor to P type simply by doping a P type dopant, it is preferable to treat the gallium nitride compound semiconductor doped with P type dopant in such process as heating in a furnace, irradiation with low-speed electron beam and plasma irradiation,

thereby to turn it to P type. After exposing the surfaces of P type and N type semiconductor layers by etching or other process, electrodes of the desired shapes are formed on the semiconductor layer by sputtering or vapor deposition.

[0033]

Then the semiconductor wafer which has been formed is cut into pieces by means of a dicing saw which has a rotating blade having diamond cutting edge, or separated by an external force after cutting grooves (half-cut) which have width greater than the blade edge width. Or otherwise, the wafer is cut into chips by scribing grid pattern of extremely fine lines on the semiconductor wafer by means of a scriber having a diamond stylus which makes straight reciprocal movement. Thus the LED chips of gallium nitride compound semiconductor can be made.

[0034]

In order to emit white light with the light emitting diode of the present invention, wavelength of light emitted by the light emitting element is preferably from 400 nm to 530 nm inclusive in consideration of the complementary color relationship with the photoluminescent fluorescent substance and deterioration of resin, and more preferably from 420 nm to 490 nm inclusive. It is further more preferable that the wavelength be from 450 nm to 4750 nm inclusive. Emission spectrum of the white light emitting diode of the present invention is shown in Fig. 3, which is the spectrum of photoluminescence having a peak at a wavelength near 570 nm,

generated by excitation by light emitted from a LED chip having a peak at a wavelength near 450 nm. A LED chip which does not excite a fluorescent substance may also be used together with the LED chip of the present invention.

[0035]

(Conductive wires 103, 203)

The conductive wires 103, 203 should have good electric conductivity, good thermal conductivity and good mechanical connection with the electrodes of the LED chips 102, 202. Thermal conductivity is preferably 0.01 cal/cm^2/cm/°C or higher, and more preferably 0.5 cal/cm2/cm/°C or higher. For workability and other reasons, the diameter of the conductive wire is preferably from Φ10 μm to Φ45 μm inclusive. The conductive wire may specifically be a metal such as gold, silver, platinum and aluminum or an alloy thereof. Such a conductive wire can be easily connected to the electrodes of the LED chips, the inner lead and the mount lead.

[0036]

(Mount lead 105)

The mount lead 105 is used for mounting of the LED chip 102, and suffices to have a size enough to load with a die bonding equipment or the like. In case a plurality of LED chips are mounted and the mount lead is used as common electrode of the LED chips, sufficient electric conductivity and good connecting characteristic with the bonding wires and the like are required. When the LED chip is mounted in the cup of the mount lead and the

cup is filled with the fluorescent substance, erroneous illumination due to light from other light emitting diode mounted nearby can be prevented.

[0037]

Bonding of the LED chip 102 and the mount lead 105 with the cup can be achieved by means of a thermoplastic resin. Specifically, epoxy resin, acrylic resin and imide resin can be used. When bonding a face-down LED chip and the mount lead and, at the same time, electrically connecting them, Ag paste, carbon paste, metallic bump or the like can be used. Further, in order to improve the efficiency of light utilization of the light emitting diode, surface of the mount lead whereon the LED chip is mounted may be mirror-polished to give reflecting function to the surface. In this case, the surface roughness is preferably from 0.1S to 0.8S inclusive. Electric resistance of the mount lead is preferably within 300 μΩ-cm and more preferably within 3 μΩ -cm. When mounting a plurality of LED chips on the mount lead, the LED chips generate significant heat and therefore high thermal conductivity is required. Specifically, the thermal conductivity is preferably 0.01 cal/cm^2/cm/°C or higher, and more preferably 0.5 cal/cm2/cm/°C or higher. Materials which satisfy these requirements include steel, copper, copper-clad steel, copper-clad tin and metallized ceramics.

[0038]

(Inner lead 106)

The inner lead 106 provides connection between the LED chip 102 mounted on the mount lead 105 and the conductive wire 103. When mounting a plurality of LED chips on the mount lead, it is necessary to employ such a construction that the conductive wires can be arranged so as not to touch each other. Specifically, contact of the conductive wires with each other which connect the inner leads that are more distant from the mount lead can be prevented by increasing the area of the end face where the inner lead is wire-bonded as the distance from the mount lead increases. Surface roughness of the end face connecting with the conductive wire is preferably from 1.6S to 10S inclusive in consideration of close contact. In order to form the tip of the inner lead in a desired shape, the shape may be formed by punching the lead frame with a die in advance, or by grinding off a part of inner leads at the top after forming all inner leads. Further, after forming by punching the inner leads, desired end face area and height can be formed simultaneously by applying pressure in the direction of end face.

[0039]

The inner lead is required to have good connectivity with the bonding wires which are conductive wires and good electrical conductivity. Specifically, the electric resistance is preferably within 300 μΩ-cm and more preferably within 3 μΩ-cm. Materials which satisfy these requirements include steel, copper, copper containing steel, copper containing tin, copper- or

silver-plated aluminum, steel or copper.

[0040]

(Coating material 101)

The coating material 101 used in the present invention is provided in the cup of the mount lead in addition to the molding material 104, and includes the photoluminescent fluorescent substance which converts the light emitted by the LED chip. As the coating material, transparent materials of excellent weatherability such as epoxy resin, urea resin and silicon and glass are preferably employed. An dispersant may be used together with the photoluminescent fluorescent substance. As the dispersant, barium titanate, titanium oxide, aluminum oxide, silicon dioxide and the like are preferably used.

[0041]

(Molding material 104)

The molding 104 may be provided in order to protect the LED chip 102, the conductive wire 103 and the coating material 101 which includes photoluminescent fluorescent substance from external disturbance, depending on the application of the light emitting diode. The molding material can be generally made of a resin. While the angle of view can be increased by containing the photoluminescent fluorescent substance, the angle of view can be further increased by adding a dispersant in the resin molding thereby making the directivity of the emission from the LED chip 102 dull. Further, the molding material 104 may be formed in a

desired shape having the function of lens to focus or diffuse the light emitted by the LED chip. Therefore, the molding material 104 may be made in a structure of multiple layers laminated. Specifically, it may be a convex lens or a concave lens, and may have an elliptic shape, or a combination thereof. As the molding material 104, transparent materials of excellent weatherability such as epoxy resin, urea resin and silicon resin, and glass are preferably employed. As the dispersant, barium titanate, titanium oxide, aluminum oxide, silicon dioxide and the like are preferably used. In addition to the dispersant, photoluminescent fluorescent substance may also be contained in the molding material. Therefore, the photoluminescent fluorescent substance may be contained either in the molding material or in the coating material and other part. Or otherwise, the coating may be of other materials such as a resin containing photoluminescent fluorescent substance and the molding material may be glass. In this case, such a light emitting diode can be made that is suited to mass production and is less affected by moisture. The molding and the coating may also be made of the same material in consideration of the refractive index. According to the present invention, the addition of the dispersant and/or a coloration agent in the molding material has the effects of masking the color of the fluorescent substance and improving the color mixing performance.

[0042]

(Display device)

When the light emitting diode of the present invention is used in a LED display, it provides display of white color of higher definition than a LED display device made by simply combining light emitting diodes which emit light of RGB colors. It is because, while a conventional device displays white light by means of three light emitting diodes, single device of the present invention can display white light. That is, in order to display white light by combining light emitting diodes and mixing light of different colors with the conventional display device, light emitting diodes of RGB colors must be illuminated at the same time. Thus the display area for each pixel becomes larger compared to the case of monochromatic display of red, green and blue colors. Therefore, high definition cannot be achieved when displaying with white light compared to the case of monochromatic display of RGB colors. Also because display with white light is achieved by controlling the emission power of the individual light emitting diodes, temperature characteristics of the semiconductors must be taken into consideration. Moreover, because the display is produced by mixing different colors, the light emitting diodes of RGB colors may be partially blocked resulting in changing display color, depending on the direction and angle of view with respect to the LED display.

The display device which employs the light emitting diode of the present invention instead of the light emitting diodes of RGB colors is capable of achieving display with higher definition, stable display of white light and reduce unevenness in color. The

light emitting diode of the present invention can also be used together with the RGB light emitting diodes. This display device is capable of improving the luminance.

[0043]

A LED display employing the light emitting diode of the present invention is shown in Fig. 5. The LED display device shown in the figure employs only the light emitting diode of the present invention and is used in a black and white LED display. The black and white LED display has only the light emitting diode 501 of the present invention arranged in matrix construction. The display device comprising the LED display shown in the figure is not provided with RGB light emitting diodes. Therefore, it does not need a plurality of drive circuits for the RGB light emitting diodes. It can drive the LED display by means of a drive circuit for white light emitting diode, instead of the plurality of drive circuits.

[0044]

The LED display is electrically connected with a lighting circuit which is a drive circuit. By means of output pulses of the drive circuit, display device capable of displaying various images can be achieved. The drive circuit is shown in Fig. 6. The drive circuit has a RAM (Random Access Memory) 603 which is video data storing means for temporarily storing the input display data, a tone control circuit 604 which processes the data stored in the RAM 603 to compute tone signals for lighting the light emitting diodes of the LED display device 1 with specified brightness and

a driver 602 which is switched by the output signal of the tone control circuit 604 to cause the light emitting diodes to illuminate. The tone control circuit 604 computes the duration of lighting the light emitting diodes of the LED display 1 from the data stored in the RAM 603, and outputs pulse signals for turning on and off the light emitting diodes.

[0045]

Thus the black and white LED display is, unlike the full-color RGB display device, capable of simplifying the circuit construction and achieving high definition display. Therefore, it can provide a display free from color unevenness due to the characteristics of the light emitting diodes, at a lower cost. It also imposes less stimulation to the eye compared to the conventional LED display which employs only red and green colors, and is suited for use over a long period of time.

[0046]

The light emitting diode of the present invention can also be used in conjunction with RGB light emitting diodes. The LED display is electrically connected with a lighting circuit which is a drive circuit. By means of output pulses of the drive circuit, display device capable of displaying various images can be achieved. The drive circuit has, similarly to a case of monochrome display device, a RAM (Random Access Memory) which is video data storing means for temporarily storing the input display data, a tone control circuit which processes the data stored in the RAM to compute tone

signals for lighting the light emitting diodes with specified brightness and a driver which is switched by the output signal of the tone control circuit to cause the light emitting diodes to illuminate. The drive circuit is required exclusively for each of the RGB light emitting diodes and the white light emitting diode. The tone control circuit computes the duration of lighting the light emitting diodes from the data stored in the RAM, and outputs pulse signals for turning on and off the light emitting diodes. When displaying with white light, width of the pulse signals for lighting the RGB light emitting diodes is made shorter, or peak value of the pulse signal is made lower or no pulse signal is output at all. On the other hand, a pulse signal is given to the white light emitting diode in compensation thereof. This causes the LED display to display with white light.

[0047]

Therefore, it is preferable that a CPU be provided separately as a tone control circuit which computes the pulse signal for lighting the white light emitting diode with specified brightness. The pulse signal which is output from the tone control circuit is given to the white light emitting diode driver thereby to switch the driver. The white light emitting diode illuminates when the driver is turned on, and goes out when the driver is turned off.

[0048]

(Signal)

When the light emitting diode of the present invention is used as a signal which is a kind of display device, such advantages can be obtained as stable illumination over a long period of time and no color unevenness even when part of the light emitting diodes go out. The signal employing the light emitting diode of the present invention has such a construction as white light emitting diodes are arranged on a substrate whereon a conductive pattern is formed. A circuit of light emitting diodes wherein such light emitting diodes are connected in series or parallel is as a set of light emitting diodes. Two or more sets of light emitting diodes are used, each having the light emitting diodes arranged in spiral construction. When all light emitting diodes are arranged, they are arranged over the entire area in circular construction. After connecting power lines by soldering for the connection of the light emitting diodes and the substrate with external power supply, it is secured in a chassis of railway signal. The LED display is placed in an aluminum diecast chassis equipped with a light blocking member and is sealed on the surface with silicon rubber filler. The chassis is provided with a white color lens on the display plane thereof. Electric wiring of the LED display is passed through a rubber packing on the back of the chassis, with the inside of the chassis closed. Thus a signal of white light is made. A signal of higher reliability can be made by dividing the light emitting diodes of the present invention into a plurality of groups and arranging them in a spiral construction swirling from a center

toward outside, while connecting them in parallel. The construction of swirling from a center toward outside may be either continuous or intermittent. Therefore, desired number of the light emitting diodes and desired number of the sets of light emitting diodes can be selected depending on the display area of the LED display. This signal is, even when one of the sets of light emitting diodes or part of the light emitting diodes fail to illuminate due to some trouble, capable of illuminate evenly in a circular construction by means of the remaining set of light emitting diodes or remaining light emitting diodes. Also it is free from color shift. Because the light emitting diodes are arranged in a spiral construction, they can be arranged more densely near the center, and driven without difference from signals employing incandescent lamps.

[0049]

(Planar light source)

The light emitting diode of the present invention can also be used to make a planar light source as shown in Fig. 7. The light emitting diode of the planar light source shown in the figure has photoluminescent fluorescent substance contained in the coating material and a diffuser sheet 706 provided on an optical waveguide plate. Or otherwise the photoluminescent fluorescent substance may be applied onto the diffuser sheet 706 together with a binder resin to form into a sheet, while omitting the molding material. Specifically, the LED chip 702 is secured in a metal

substrate 703 of inverted C shape whereon an insulation layer and a conductive pattern are formed. After electrically connecting the LED chip and the conductive pattern, photoluminescent fluorescent substance is mixed with an epoxy resin and applied onto the metal substrate 703 whereon the LED chip 702 is mounted. The LED chip thus secured is fixed onto an end face of an acrylic waveguide plate 704 by means of the epoxy resin or the like. A reflector film 707 containing a white diffusion agent is arranged on one of principal planes of the optical waveguide plate 704 for the purpose of preventing fluorescence. Similarly, a reflector 705 is provided on the entire surface on the back of the optical waveguide plate and on one end face where the LED chip is not provided, in order to improve the light emission efficiency. With this construction, light emitting diodes can make a planar light source which generates enough luminance for the back light of LCD. Application to a liquid crystal display can be achieved by arranging a polarizer plate on the principal plane of the optical waveguide plate 704 via liquid crystal injected between glass substrates whereon a translucent conductive pattern not shown in the drawing is formed. Examples of the present invention will be described below. It should be understood that the present invention is not limited to the Examples.

[0050]

[Example]

(Example 1)

A GaInN semiconductor having emission peak at 450 nm was used as a light emitting element. A LED chip was made by flowing TMG (trimethyl gallium) gas, TMI (trimethyl indium) gas, nitrogen gas and dopant gas together with a carrier gas on a cleaned sapphire substrate and forming a gallium nitride compound semiconductor layer in the MOCVD process. A gallium nitride semiconductor having N type conductivity and a gallium nitride semiconductor having P type conductivity are formed by switching SiH_4 and Cp_2Mg as dopant gas, thereby forming a PN junction. The P type semiconductor was annealed at a temperature of 400 °C or above after forming the film.

[0051]

After exposing the surfaces of P type and N type semiconductor layers by etching, electrodes were formed by sputtering. After scribing the semiconductor wafer which has been made as described above, LED chips were made as light emitting elements by dividing the wafer with external force.

[0052]

The LED chip was mounted on a mount lead having a cup at the tip of a silver-plated copper lead frame, by die bonding with epoxy resin. Electrodes of the LED chip, the mount lead and inner lead are electrically connected by wire boding with gold wires.

[0053]

On the other hand, photoluminescent fluorescent substance was made by dissolving rare earth elements of Y, Gd and

Ce in an acid in stoichiometrical proportions, and coprecipitating the solution with oxalic acid. Oxide of the coprecipitate obtained by sintering this material was mixed with aluminum oxide, thereby to obtain the mixture material. The mixture was then mixed with ammonium fluoride used as a flux, and sintered in a crucible at a temperature of 1400 °C in air for 3 hours. Then the sintered material was ground by ball mill in water, washed, separated, dried and sieved thereby to obtained the desired material.

[0054]

80 Parts by weight of the fluorescent substance having a composition of $(Y_{0.8}Gd_{0.2})_5Al_5O_{12}$:Ce which has been made and 100 parts by weight of an epoxy resin were well mixed to form a slurry. The slurry was poured into the cup provided on the mount lead whereon the LED chip was mounted. After pouring, the resin containing photoluminescent fluorescent substance was cured at 130 °C for one hour. Thus a coating 120 μm thick containing the photoluminescent fluorescent substance was formed on the LED chip. Concentration of the photoluminescent fluorescent substance in the coating was tapered to increase toward the LED chip. The LED chip and the photoluminescent fluorescent substance were molded with translucent epoxy resin for the purpose of protection against extraneous stress, moisture and dust. A lead frame with the coating layer of photoluminescent fluorescent substance formed thereon was placed in a bullet-shaped die and mixed with translucent epoxy resin and then cured at 150 °C for 5 hours. Under visual observation of

the light emitting diode formed as described above in the direction normal to the light emitting plane, it was found that the central portion was rendered yellowish color due to the body color of the photoluminescent fluorescent substance.

[0055]

Measurements of chromaticity point, color temperature and color rendering index of the light emitting diode capable of emitting white light gave values of (0.302, 0.280) for chromaticity point (x, y), color temperature of 8080K and 87.5 for Ra (color rendering index) which are approximate to the characteristics of a 3-waveform fluorescent lamp. Light emitting efficiency of 9.51 m/W comparable to that of an incandescent lamp was obtained. Further in life tests under conditions of energization with a current of 60 mA at 25 °C, 20 mA at 25 °C and 20 mA at 60 °C with 90% RH, no change due to the fluorescent substance was observed, proving that the light emitting diode has no difference in service life from conventional blue light emitting diode.

[0056]

(Comparative Example 1)

According to the same manner as that described in Example 1 except for changing the photoluminescent fluorescent substance from $(Y_{0.8}Gd_{0.2})_5Al_5O_{12}$:Ce to (ZnCd)S:Cu, Al, the formation of a light emitting diode and life test were conducted. The light emitting diode which had been formed showed, immediately after energization, emission of white light but the luminance was low. In the life test,

the output diminished to zero in about 100 hours. Analysis of the cause of deterioration showed that the fluorescent substance was blackened.

[0057]

This trouble is supposed to have been caused as the light emitted by the light emitting element and moisture which was on the fluorescent substance or entered from the outside brought about photolysis to make colloidal zinc to precipitate on the surface of the fluorescent substance, leading to blackened surface. Results of life tests under conditions of energization with a current of 20 mA at 25 °C and 20 mA at 60 °C with 90% RH are shown in Fig. 8 together with the first embodiment. Luminance is given in terms of relative value with respect to the initial value as the reference. Solid line indicates Example 1 and wavy line indicates the Comparative Example 1.

[0058]

(Example 2)

A LED chip having emission peak at 460 nm was made by increasing the content of In in the nitride compound semiconductor compared to that of Example 1. The photoluminescent fluorescent substance was made according to the same manner as that described in Example except for increasing the content of Gd than that of Example 1 to have a composition of $(Y_{0.6}Gd_{0.4})_5Al_5O_{12}$:Ce, and 100 light emitting diodes were made to conduct the life test.

[0059]

Measurements of chromaticity point, color temperature and color rendering index of the light emitting diodes capable of emitting white light, which were made as described above, gave values of (0.375, 0.370) for chromaticity point (x, y), color temperature of 4400K and 86.0 for Ra (color rendering index). Further in life tests, 100 light emitting diodes were averaged. Average luminous intensity was taken after 1000 hours in percentage of the luminous intensity value before the life test. The average luminous intensity after the life test was 98.8%, proving no difference in the characteristic.

[0060]

(Example 3)

100 light emitting diodes were made according to the same manner as that described in Example 1 except for adding Sm in addition to rare earth elements Y, Gd and Ce in the photoluminescent fluorescent substance to make a fluorescent substance have the composition of $(Y_{0.39}Gd_{0.57}Ce_{0.03}Sm_{0.01})_3Al_5O_{12}$. When the light emitting diodes were made illuminate at a high temperature of 130 °C, average temperature characteristic about 8% better than that of Example 1 as obtained.

[0061]

(Example 4)

The light emitting diode of the present invention was used in one of LED display devices as shown in Fig. 5. The light emitting diodes made according to the same manner as that described

in Example 1 were arranged in a 16x16 matrix on a ceramics substrate whereon a copper pattern was formed. The light emitting diodes were soldered onto the substrate by means of an automatic soldering machine, and the assembly thus made was placed in a chassis 504 made of phenol resin and secured. A light blocking material 505 is formed integrally with the chassis. The chassis, the light emitting diodes, the substrate and part of the light blocking material, except for the tips of the light emitting diodes, were covered with silicon rubber 406 colored in black with a pigment. Then the silicon rubber was cured at the normal temperature for 72 hours, thereby to form the LED display device. The LED display device, a RAM (Random Access Memory) which temporarily stores the input display data, a tone control circuit which processes the data stored in the RAM to compute tone signals for lighting the light emitting diodes with specified brightness and CPU drive means which is switched by the output signal of the tone control circuit to cause the light emitting diodes to illuminate were electrically connected to make a LED display device. By driving the LED display devices, it was verified that the device can be used as black and white LED display device.

[0062]

[Effect of the invention]

According to the present invention, by combining light emitting element of nitride compound semiconductor, yttrium-aluminum-garnet fluorescent substance activated with cerium and

$(RE_{1-x}Sm_x)_3(Al_yGa_{1-y})_5O_{12}$:Ce fluorescent substance, a light emitting diode having a high emission efficiency even after operation with high luminance over a long period of time can be made. With high reliability, energy saving performance, compact construction and capability to change color temperature, the light emitting diode of the present invention can open up new applications as illumination in addition to display in automobile, aircraft and electric appliances in general. Particularly the photoluminescent fluorescent substance used in the present invention can also be used as a light source having response speed of 120 nsec, because the after glow remains only for a short period of time. Also the light emitting diode of the present invention is better for the human eyes because white light imposes less stimulation to the eye when watched for a long period of time.

[0063]

The construction described in claim 1 or 3 of the present invention, in particular, makes it possible to obtain various light emitting diodes capable of emitting white light with high luminance, minimum color shift and minimum deterioration in light emission efficiency even when used over an extended period of time. Decrease in the luminance due to deterioration of the resin can also be suppressed.

[0064]

The construction described in claim 5 of the present invention makes it possible to obtain various light emitting diodes

having high luminance, minimum color shift and minimum deterioration in light emission efficiency even when used over an extended period of time. Decrease in the luminance due to deterioration of the resin can also be suppressed. In addition, even when a plurality of light emitting diodes are mounted close to each other, erroneous illumination due to excitation of fluorescent substance by light from other light emitting diode mounted nearby can be prevented. Because unevenness in emission of the LED chip itself can be smoothed out by the fluorescent substance, the light emitting diode can emit light uniformly.

[0065]

The construction described in claim 6 of the present invention makes it possible to obtain alight emitting diode having less temperature dependency.

[0066]

The construction described in claim 7 of the present invention makes it possible to made a relatively low-priced LED display device of high definition and a LED display device which shows less unevenness in color regardless of the angle of view.

[0067]

[Brief Description of the Drawings]

[Fig. 1] Fig. 1 is a schematic sectional view of the light emitting diode of the present invention.

[Fig. 2] Fig. 2 is a schematic sectional view of another light emitting diode of the present invention.

[Fig. 3] Fig. 3 shows one embodiment of emission spectrum of the light emitting diode of the present invention.

[Fig. 4] Fig. 4(A) shows one embodiment of absorption spectrum of the photoluminescent fluorescent substance used in the present invention, and Fig. 4(B) shows one embodiment of emission spectrum of the photoluminescent fluorescent substances used in the present invention.

[Fig. 5] Fig. 5 schematically shows the LED display device employing the light emitting diode of the present invention.

[Fig. 6] Fig. 6 is a block diagram of the LED display device of Fig. 5.

[Fig. 7] Fig. 7 schematically shows another LED display device employing the light emitting diode of the present invention.

[Fig. 8] Fig. 8(A) shows the results of the life test conducted for the comparison of Example 1 of the present invention with the light emitting diode of Comparative Example 1 under conditions of energization with a current of 20 mA at 25 °C, while Fig. 8(B) shows the results of the life test conducted for the comparison of Example 1 of the present invention with the light emitting diode of Comparative Example 1 under conditions of energization with a current of 20 mA at 60 °C and 90%RH.

[Description of the Reference Numerals]

101, 701: Coating material wherein photoluminescence is contained

102, 202, 702: LED chip

103, 203: Conductive wire

104: Molding material

105: Mount lead

106: Inner lead

201: Molding material wherein photoluminescence is contained

204: Casing

205: Electrodes provided on casing

501: Light emitting diode

504: Casing

505: Light blocking material

506: Filling material

601: LED display device

602: Driver

603: RAM

604: Tone control means

703: Metallic substrate

704: Optical waveguide plate

705, 707: Reflective material

706: Diffusion sheet

Fig. 1

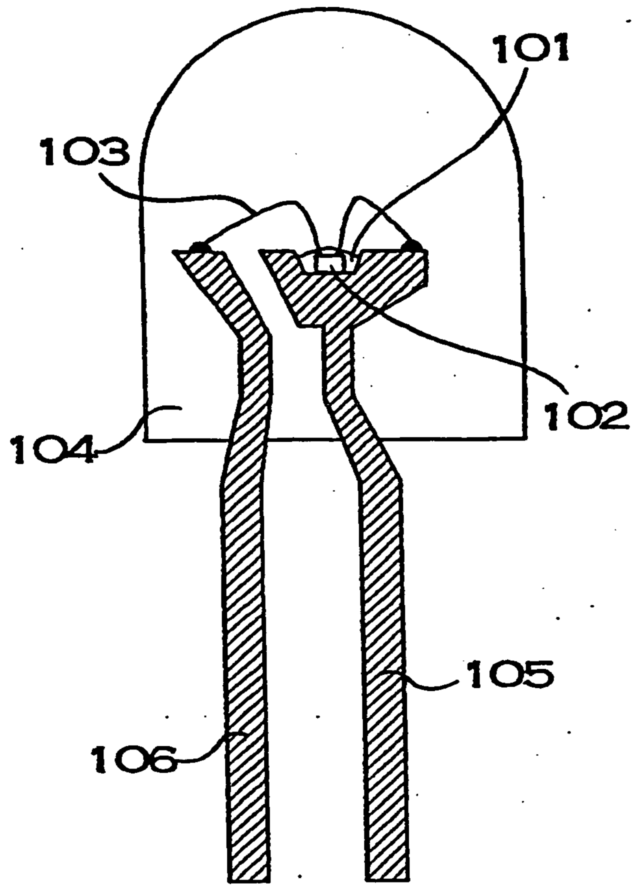


Fig. 2

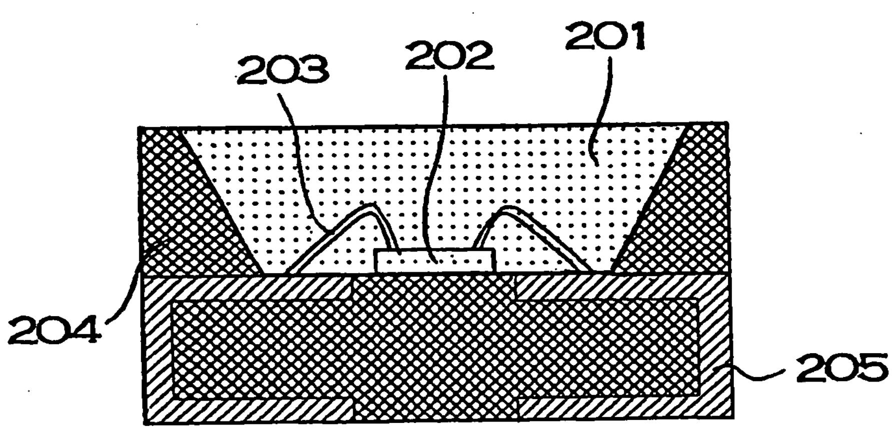
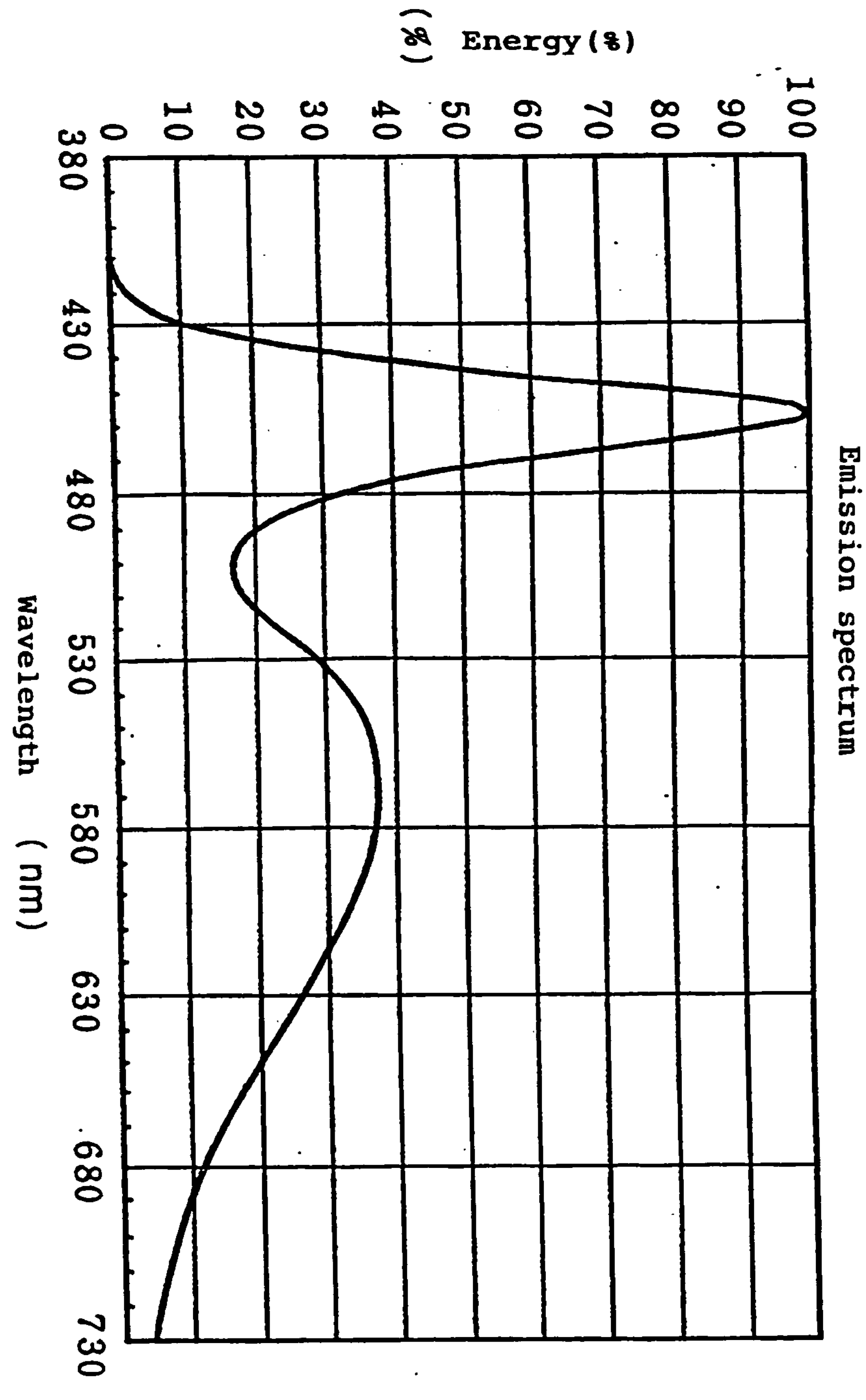
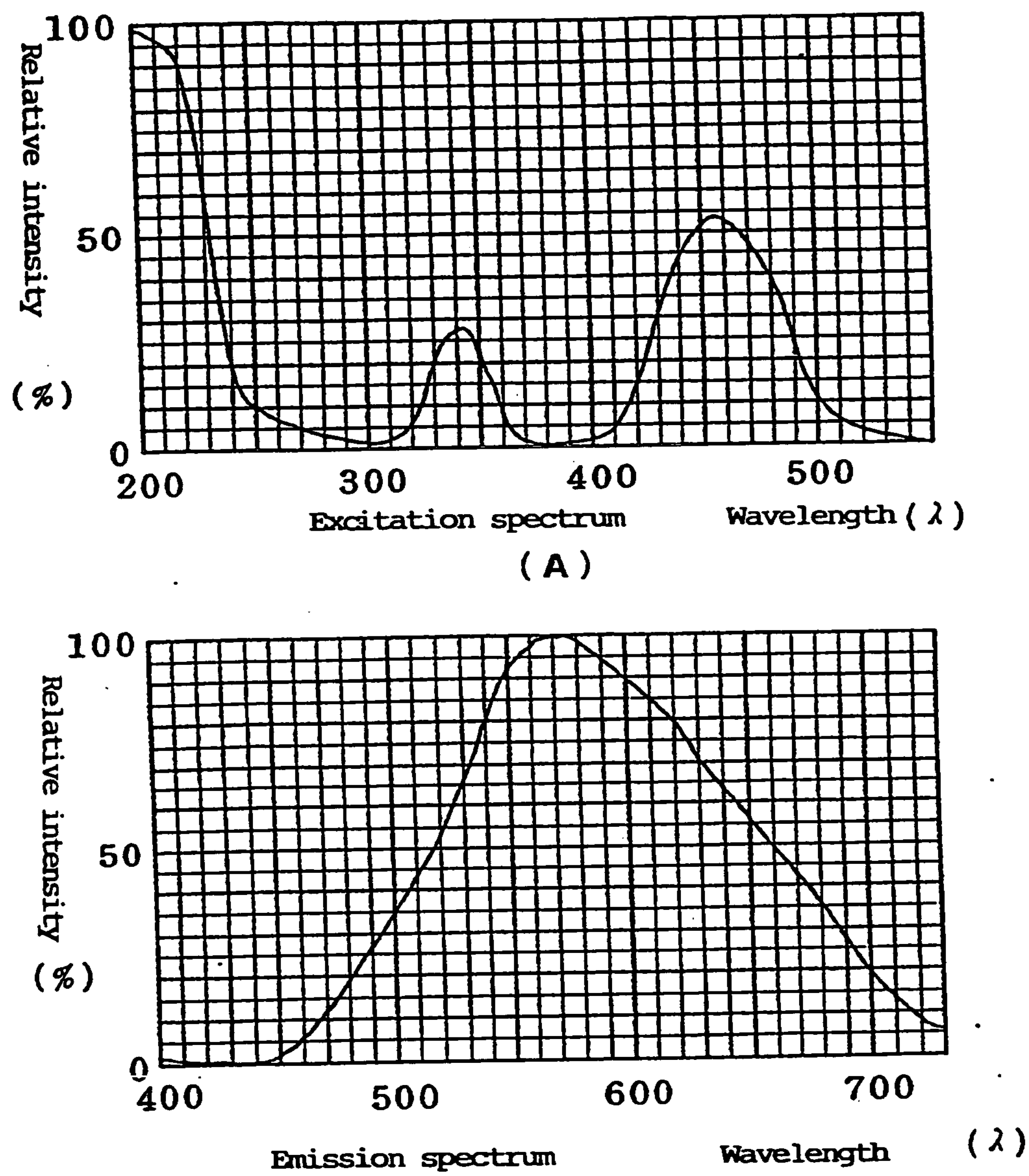


Fig. 3



Emission spectrum
Energy(%)
(%)
0
10
20
30
40
50
60
70
80
90
100
380
430
480
530
580
630
680
730
Wavelength (nm)

Fig. 4



100
50
0
Relative intensity
(%)
200
300
400
500
Excitation spectrum
Wavelength (λ)
100
50
0
Relative intensity
(%)
400
500
600
700
Emission spectrum
Wavelength
(λ)

(A)

(B)

Fig. 5

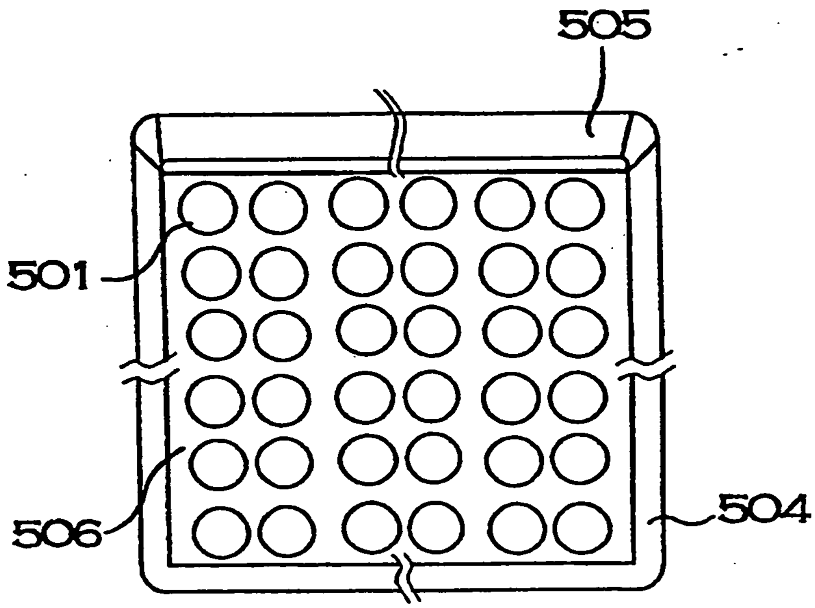


Fig. 6

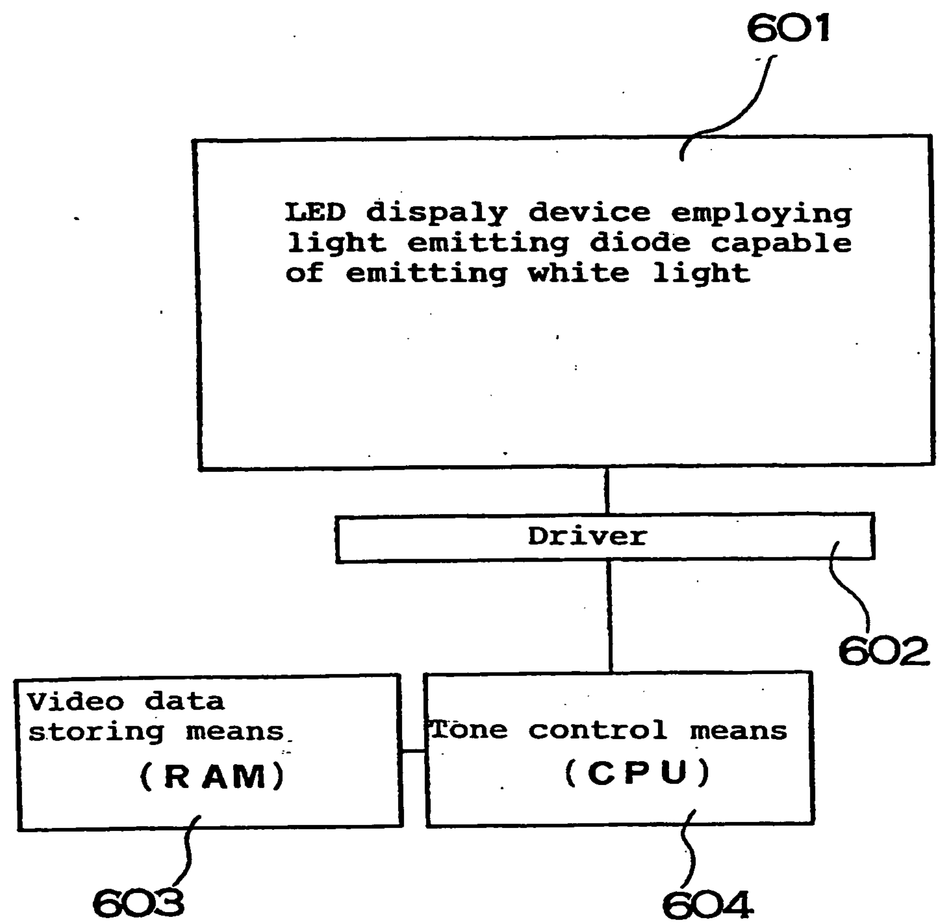

601
LED dispaly device employing light emitting diode capable of emitting white light
Driver
602
Video data storing means (RAM)
Tone control means (CPU)
603
604

Fig. 7

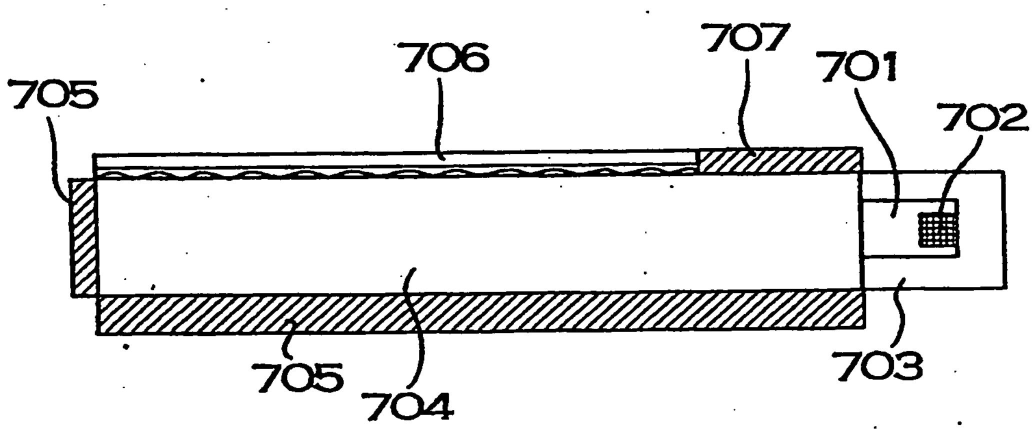
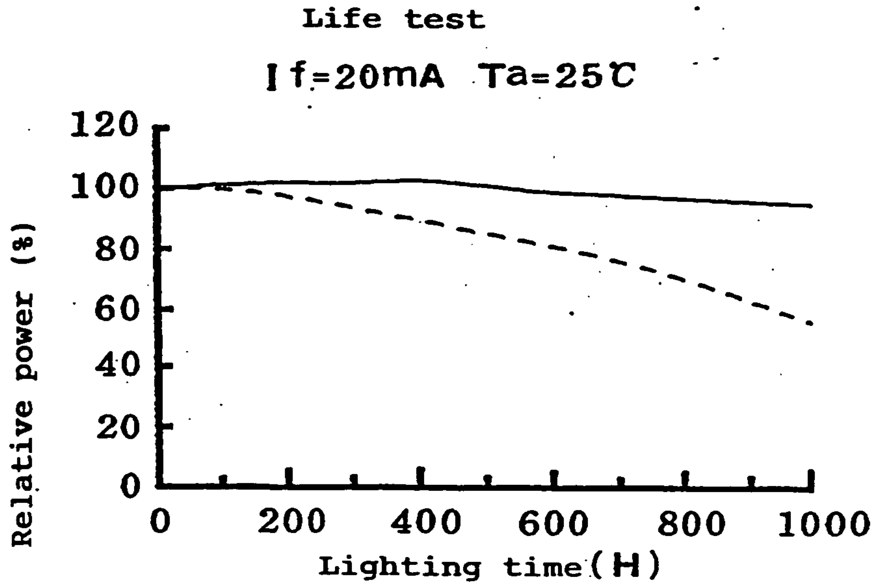
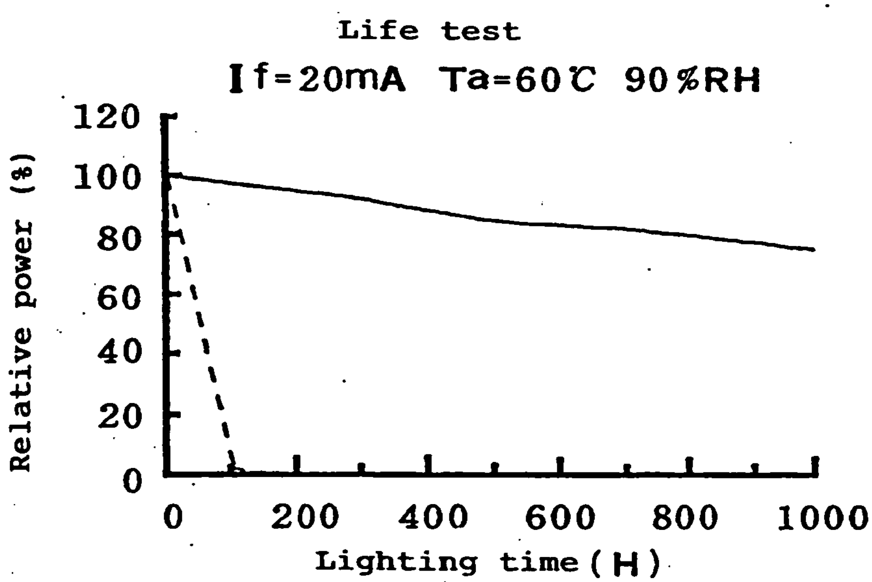

705
706
707
701
702
705
704
703

Fig. 8


Life test
If=20mA Ta=25℃
120
100
80
60
40
20
0
Relative power (%)
0
200
400
600
800
1000
Lighting time (H)

(A)


Life test
If=20mA Ta=60℃ 90%RH
120
100
80
60
40
20
0
Relative power (%)
0
200
400
600
800
1000
Lighting time (H)

(B)

[Document Name] Abstract

[Abstract]

[Object] It is to minimize the decrease of light emission efficiency and the shift of color even under operation with high luminance over a long period of time.

[Means for solving] The light emitting diode has a LED chip and photoluminescent fluorescent substance which absorbs at least a part of the light emitted by the LED chip to emit light by converting the wavelength. The LED chip is a nitride compound semiconductor and the photoluminescent fluorescent substance is yttrium-aluminum-garnet fluorescent substances activated with cerium.

Document Name: Official Correcti n Data

Corrected Document: Petition for Patent

Approved or Supplemented Data:

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